PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : H01M 10/48

A1

(11) International Publication Number: WO 90/15450

(43) International Publication Date: 13 December 1990 (13.12.90)

(21) International Application Number: PCT/US90/03052

(22) International Filing Date: 31 May 1990 (31.05.90)

(30) Priority data:
359,642 31 May 1989 (31.05.89) US

(71) Applicant: AMOCO CORPORATION [US/US]; 200 East Randolph Drive, Chicago, IL 60680-0703 (US).

(72) Inventors: LIMUTI, Donald ; 109 Lake Street South, Apt. #4, Kirkland, WA 98033 (US). ROSS, James, M., Jr. ; 9827 N.E. 204 Place, Bothell, WA 98011 (US). CHURCHILL, Thomas, L. ; 820 Riverside Drive, S.E., North Bend, WA 98045 (US).

(74) Agents: STORWICK, Robert, M. et al.; Seed and Berry, 6300 Columbia Center, Seattle, WA 98104-7092 (US).

(81) Designated States: AT (European patent), AU, BE (European patent), CA, CH (European patent), DE (European patent)*, DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

Reg.

(54) Title: ELECTROLYTIC STORAGE CELL MONITORING SYSTEM

(57) Abstract

Sensors capable of measuring various electrolytic parameters such as voltage, state-of-charge, electrolyte level, internal resistance, and temperature are attached to a monitoring module which gathers and processes signals representative of information concerning the electrolytic condition of electrolytic storage cells and transmits the information to a central computer for further processing. In response to commands issued by the central computer, appropriate maintenance and/or repair operations can be initiated. Alternatively, the system described can be used to automatically perform such maintenance tasks as checking and adding electrolyte levels, reducing the voltage whose output voltage is too high, and leveling the state-of-charge of each cell in an array of electrolytic storage cells. The system can monitor other functions of the electrolytic storage cells, including the evolution of hydrogen gas and the accumulation of sediments in individual electrolytic storage cells.

* See back of page

DESIGNATIONS OF "DE"

Until further notice, any designation of "DE" in any international application whose international filing date is prior to October 3, 1990, shall have effect in the territory of the Federal Republic of Germany with the exception of the territory of the former German Democratic Republic.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MC	Monaco
AU	Australia	FI	Finland	MG	Madagascar
BB	Barbados	FR	France	ML	Mali
BE	Belgium	GA	Gabon	MR	Mauritania
BF	Burkina Fasso	GB	United Kingdom	MW	Malawi
BG	Bulgaria	GR	Greece	NL	Netherlands
BJ	Benin	HU	Hungary	NO	Norway
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	SD	Sudan
CF	Central African Republic	KP	Democratic People's Republic of Korea	SE	Sweden
CG	Congo	KR	Republic of Korea	SN	Senegal
CH	Switzerland	LI	Liechtenstein	SU	Soviet Union
CM	Cameroon	LK	Sri Lanka	TD	Chad
DE	Germany, Federal Republic of	LU	Luxembourg	TG	Togo
DK	Denmark			US	United States of America

ELECTROLYTIC STORAGE CELL MONITORING SYSTEM

Technical Field

This invention relates to a monitoring system, and more particularly, to a system for monitoring a plurality of electrolytic storage cells.

Background Art

Most major installations in the United States that use electrical power have backup systems in case the normal electrical supply becomes disabled. Typical examples include large office buildings, hospitals, public utility systems, and municipal facilities. Frequently, the source of the backup electrical power is a bank of interconnected electrolytic storage cells, such as the common lead-acid storage cell, which retain electrical charge for conversion to electrical current. Since it is often unpredictable when such systems will be called upon to supply their emergency function, it is critical that they be maintained at or near their greatest possible efficiency. Accordingly, the users of such systems have frequently put in place preventive maintenance and/or repair procedures.

Among the popular present methods for maintaining and/or repairing a large array of storage cells are: 1) to wait until some cell in the array fails; 2) to periodically replace the cells in the array, thereby reducing the chance that any one of the cells will fail when the array is called upon for its emergency purpose; or 3) to periodically test each cell in the array. A problem with the first method is that great expense can be incurred should the array fail when it is needed. A problem with second method is that it may be unnecessarily expensive and wasteful to periodically replace cells that may not be defective. A problem with the third method is that each individual cell must be separately checked with intrusive tests of the cell's electrolyte, which is typically a combination of various fluids such as water (H2O) and sulphuric acid (H2SO4).

Accordingly, it would be useful to have a method for monitoring and maintaining such arrays when and only when such services are required.

Disclosure of the Invention

It is an object of the present invention to provide an apparatus for nonintrusively monitoring electrolytic parameters of one or more electrolytic storage cells.

It is another object of the present invention to provide an apparatus for nonintrusively detecting the level of an electrolyte in a storage cell.

It is yet another object of the present invention to provide an apparatus for nonintrusively detecting the specific gravity of an electrolyte in a storage cell.

It is still another object of the present invention to provide an apparatus for nonintrusively detecting the state-of-charge of a storage cell.

Yet another object of the present invention is to provide an apparatus including one or more sensors that comprise a circuit for nonintrusively measuring the voltage, internal resistance, and the temperature of a storage cell.

Still another object of the present invention is to provide a system of storage cells, including a monitoring module attached to each storage cell and means for addressing each monitoring module to collect signals representing the electrolytic condition of each storage cell.

Still another object of the present invention is to provide a system including means for bringing the storage cells to a desired state of charge.

An even further object of the present invention is to provide an apparatus including means for nonintrusively measuring the evolution of by-products resulting from charging the storage cell.

An even further object of the present invention is to provide an apparatus for measuring the level of sediment at the bottom of the enclosure of a storage cell.

Still another object of the present invention is to provide an apparatus for adjusting a level of the electrolyte in each storage cell in an array of storage cells.

An additional object of the present invention is to provide an apparatus for causing an array of storage cells to be bought to a desired state-of-charge by means of balancing the state-of-charge of each storage cell in the array of storage cells.

According to one aspect, the invention provides a system for monitoring electrolytic parameters of one or more electrolytic storage cells. The system comprises a monitoring module associated with each storage cell, means for addressing each monitoring module to collect signals representing the electrolytic parameters of the associated storage cell, means for addressing each monitoring module to collect the signals representing the electrolytic condition of each storage cell, and means for processing the signals to monitor the

condition of each storage cell. The monitoring module comprises one or more sensors attached to the enclosure of the associated storage cell and means for producing signals representing the electrolytic parameters of the associated storage cell.

In another aspect, the present invention provides a system for monitoring electrolytic parameters of one or more electrolytic storage cells. The system comprises a monitoring module attached to each storage cell, means for addressing each monitoring module to collect signals representing the electrolytic condition of each storage cell and to transmit the command signals to the addressed monitoring module, and means for processing the signals to monitor the condition of each storage cell and for generating the command signals in response to the condition of each storage cell. Each monitoring module comprises controllable means for generating a signal containing a predetermined frequency, controllable means for measuring the complex impedance of the associated storage cell at the predetermined frequency, controllable means for producing signals representing the electrolytic parameters of the associated storage cell, communication means for transmitting and receiving signals, and a microprocessor operating under the control of a program to send the signals representing the electrolytic parameters of the associated storage cell to the communication means and to receive command signals from the communication means.

<u>Brief Description of the Figures</u>

Figure 1 is an isometric view of an electrolytic storage cell, showing a first embodiment of an apparatus for monitoring the electrolyte level of the storage cell.

Figure 2 is a schematic diagram of the electrolyte level monitor of Figure 1.

Figure 3 is a schematic diagram of a circuit for measuring the electrolyte level in the electrolytic storage cell, in accordance with the embodiment of Figure 1.

Figure 4 is an isometric view of an electrolytic storage cell, showing a second embodiment of an apparatus for monitoring the electrolyte level of the storage cell.

Figure 5 is a schematic diagram of an equivalent model of the electrolyte level monitor of Figure 4.

Figure 6 is a schematic diagram of a circuit for measuring the electrolyte level in the electrolytic storage cell, in accordance with the embodiment of Figure 4.

Figure 7 is a graph of the specific gravity and sensor impedance detected in an evaluation of the second embodiment of the apparatus, as shown in Figure 4.

Figure 8 is a graph depicting the correlation between the sensor impedance and the specific gravity of an electrolytic cell as measured by the second embodiment of the apparatus, as shown in Figure 4.

Figure 9 is a cut-away isometric view, showing an apparatus for monitoring the state-of-charge of an electrolytic storage cell.

Figure 10 is a schematic diagram of an embodiment of the apparatus of Figure 9, exemplifying electrode flux exclusion.

Figure 11A is a graph of the specific gravity and percentage frequency shift of the electrolytic storage cell shown in Figure 9 as the storage cell is subjected to significant levels of current drain, up to ten percent beyond the storage cell's rated discharge capacity.

Figure 11B is a schematic diagram of an equilvalent model of the apparatus of Figure 9.

Figure 12 is a schematic diagram of a cell voltage/cell resistance/cell temperature/bus-cell connection resistance monitoring circuit for use with an electrolytic storage cell.

Figure 13 is a schematic diagram of a circuit useful to test the internal resistance of an electrolytic storage cell.

Figure 14A is a graph of the pulse charge response of a fully charged electrolytic storage cell.

Figure 14B is a graph of the pulse charge response of an electrolytic storage cell which has been discharged ten percent beyond its rated discharge capacity.

Figure 15 is an isometric view of an electrolytic storage cell with a multi parameter monitoring package, for use in a cell monitoring system.

Figure 16 is a block diagram of one embodiment of the circuitry of the multi parameter monitoring package of Figure 15.

Figure 17 is a fragmentary isometric view illustrating part of an electrolytic storage cell array equipped with multiparameter monitoring packages of Figure 15.

Figure 18 is a schematic diagram of the comprehensive cell monitoring system of the present invention.

Detailed Description of Preferred Embodiments

Referring to Figure 1, an electrolytic storage cell 20 is contained with an enclosure 22 having a positive terminal 24 and a negative terminal 26. The enclosure 22, which contains the electrolyte for the cell 22, can be either a separate enclosure for each cell or an enclosure containing two or more storage cells 22. The terminals 24 and 26 typically extend upwardly through an upper surface 28 of the enclosure 22. A cap 30, which can be used to access the interior of the enclosure 22 to measure the specific gravity of the electrolytic cell, employing a conventional hydrometer or to adjust the electrolyte contained within the electrolytic storage cell 20, is also located on the upper surface 28. The cap 30 can be removed and replaced, according to whether the cell is to be tested or stored. The electrolytic storage cell 20 is configured to have its electrolyte monitored by a conventional printed circuit (PC) electrode array 38, which is attached to the vertical surface 36.

Figure 2 isk a schematic diagram of the capacitive electrolyte level monitor of Figure 1. The PC electrode array 38 includes a plurality of sequentially interrogated electrodes 391, ... 39N, each having a capacitance which depends on the electrode's size and composition. If each electrode 39 is a copper strip approximately one inch long and 0.1 inch wide, its capacitance will be approximately 39 picofarads. The electodes 39 are attached to the exterior vertical surface 36 of the storage cell 20. The electrodes 391, ..., 39N serve the purpose of sinking electrical currents which differ depending on whether one leg of a sequencing interrogation circuit 40 is connected to an electrode 39 which is above an electrolyte level 42 of the electrolytic storage cell 20, as opposed to below it.

Equivalently, the interrogation circuit 40 is in the form of a number of series capacitors 441, ..., 44N, formed by the capacitance between each electrode 39 and the electrolyte separated by the cell case, and connected by means of a series of parallel capacitors 461, ..., 46N, formed by the stray capacitance between adjacent electrodes 39. The effective series capacitors 44

and the effective parallel capacitors 46 which are located below the electrolyte level 42 absorb more signal than do their counterparts above the electrolyte level because of the electrical "shorting" effect of the electrolyte. This can be detected as a change in the capacitance in the consecutive capacitors 39 on the electrode array 39. Accordingly, the electrolyte level 42 can be located with a precision that is equal to the separation between consecutive electgrodes 39. If desired, electrode spacing can be varied in the ele3ctrode array 38 ain order to achieve high precision location of the electooolyte level 42 when it is at certain levels and coarser precision at other electrolyte levels 42.

Figure 3 is a schematic diagram of a first interrogation circuit 40 for testing the capactitance of the consecutive electodes 39 in the electrode array 38. The circuit 40 includes a vector impedance bridge 80 which is connected to a parallel inductor 86 and, in turn, to a pair of 1" x 0.1" copper strips 88. The copper strips 88 are arranged so that in one case both of the copper strips are above the electrolytic fluid and in another case both strips are below the electrolytic fluid. It has been discovered that, for an approxpriate choice of the inductor 86, the resonant impedance of the circuit composed of the inductor 86, a pair of consecutive electrodes 39 (in the form of copper strips 88), the cell case, and the electrolyte contained within the cell case varies considerably depending upon whether the electrodes 39 are both covered by the electrolyte or both exposed. If the electrolyte is above botrh electrodes, the resonantl impedance of the circuit is 59 kilohms (at a resonant frequency of 25.8 MHz), while if the electrolyte is below both electrodes, it falls to 25 kilohms (at a resonant frequency of 26.5 MHz). It has also been discovered that exposing the electrodes by tipping the cell requires approximately 15 minutes of evaporation time for the resonant impedance to stabilize to 25 kilohms. Resonant frequencies, and the impedance at these frequencies, can be measured by means of conventional circuitry, as exemplified by the Hewlett-Packard impedance bridge 80.

Figure 4 is an isometric view of the electrolytic storage cell 20 configured to have its electrolyte monitored by two sense coils 32 and 34. Both the level and the specific gravity of the electrolyte can be monmitored by the appaatus shown in Figure 4. A fluid level sense coil 32 (which will be explained in greater detail subsequently) is attached to a vertical surface 36 of the enclosure 22 at a level which is appropriate for the range of electrolyte levels

that can be expected in normal operation of the electrolyte storage cell 20. In addition, a specific gravity sense coil 34 is placed on the vertical surface 36 at a level to which it is not expected that the electrolyte level will fall.

Figure 5 of the drawings shows a model of a circuit including both of the sense coils 32 and 34 shown in Figure 4. The model consists of a collection of capacitors, resistors, and inductors. The model can be shown, by conventional transient circuit analysis of the actual and virtual (image) currents produced when the sense coils 32 and 34 are caused to resonate, to have a characteristic response in the form of a damped sinusoid. The sense coils 32 and 34 generate oppositely directed image currents corresponding to their respective locations. Both the damping rate and the characteristic (resonant) frequency of the circuit are characteristic of aspects of the model, including the resistancdes of the copper (RCu) and the electolyte (RH2SO4) as well as the inductances of the two sensor coils 32 and 34. These can be related to the electrolyt level and the specific gravity of the electrolyte.

Figure 6 illustrates circuitry capable of testing the circuit composed of the two inductive sensor coils 32 and 34. A vector impedance bridge 80 produces a signal which is received by a capacitor 82 and a ten turn coil 84 (which can be rectangular, one inch high and two inches wide and can represent either of the sensor coils 32 or 34). The ten turns in the coil 84 are grouped into to five turn coils, one positioned above the other. If the fluid in the electrolytic storage cell 20 is above both of the coils located along the electrolytic cell, the circuit hasw a resonant impedance of 7.5 kilohms at 6.3 MHz. If, however, the fluid is below both of the coils, the resonant impedance rises to 22 kilohms at a frequency of 6.1 MHz. It was noticed that the resonant impedance measurement stabilizes after no noticeable delay if the cell is tipped to place the fluid level berlow the two coils.

Figure 7 is a graph showing the response of a sense coil 34 (see Figure 4) as the specific gravity of the electrolyte, as measured by a hydrometer, decreases. The circuit shown in Figure 5 is driven by a sinusoidal voltage at a frequency of approximately 6 MHz. The specilfic gravity decreases while the sensor impedance increases progressively with elapsed discharge time over a period of eleven hours at a discfharge current of 11.7 amperes.

Figure 8 is a composite figure cross-plotting the values of specific gravity and sensor impedance, according to the parameters of the pair of sensors

coils 32 and 34. The sensor impedance and specific gravity are approximatley inversly related. As the specific gravity of the electrolytic cell decreases, the resonant impedance of the sensor coil increases.

Figure 9 illustrates a state-of-charge monitoring circuit for use with the electrolyte storage cell 20. The state-of-charge is measured as the integral over the voluyme of the cell 20, of the square of the B-field withing the cell 20. The cell 20 includes a multi-turn sense coil 50 which is used to monitor the state-of-charge. The coil 50 surrounds the enclosrue of the cell 20 in a horizontal plane, and is closely adjacent to the vertical surfaces 36 of the cell 20.

The enclosure 22 of the electrolytic storage cell 20 contains a plurality of parallel plates 52, which, in a lead-acid storage cell, are composed of lead. Driving the coil 50 by a sinusoidal voltage in the range of approximately 100 kHz creates magnetic fields within the enclosure. The inductance of the coil 50, and hence its resonant frequency, is affected by the state of charge of the cell 20. The magnetic fields imposed by the coil 50 induce currents within the parallel plates 52. The currents reside in the electrolyte and close to the surface of the outer-most plates, at a depth that is related to the frequency of excitation of the coil 50. If the skin depth in the plate is less than half the plate's thickness and the skin depth in the electrolyte that is greater than the width of the storage cell 20, the state-of-charge of the electrolytic storage cell 20 is roughly proportional to the negative change in the inductance of the sense coil 50. The reason is that the inductance change is proportional to the negative of the flux-excluded volume change, which is roughly proportional to the change in the electrode volume. Since the electrically conducting lead plates are partially converted to electrically insulating lead sulfide during cell discharge, the cell's inventory of lead, hence its flux-excluded volume, is a measure of the cell's state of change.

Figure 10 schematically depicts the cross section of an electrolytic cell 20 and the sense coil 50, showing the applied and circulating currents and the orthogonal distribution of magnetic flux 54, the latter excluded from the lead plates by the skin depth of the circulating currents.

Figure 11A is a graph of the specific gravity and the frequency shift in a resonant frequency circuit (shown in Figure 11B) representing the coil/cell configuration shown in Figures 9 and 10, as functions of the amount of charge removed from the electrolytic storage cell 20. The coil 50 is operating at

a frequency of 116 kHz and the cell 20 is being discharged at a rate of 40 amperes. It is clear that the frequency shift and specific gravity of a given electrolytic storage cell 20 run closely parallel to one another. Accordingly, it is possible to monitor specific gravity in the cell by measuring the change in the resonant frequency of the cell/coil combvination relative to the resonant frequency before the cell was discharged.

Figure 11B is the electrical circuit which models the coil/cell combination shown in Figures 9 and 10. This model can be obtained through conventional transient circuit analysis.

Figure 12 is a schematic diagram of a circuit 70 for monitoring the cell voltage, cell resistance, cell temperature, and bus-cell connection resistance of the electrolytic storage cell 20. The circuit 70 operates on the principle of a pulse discharge of the storage cell 20 through its terminals 24 and 26, which are attached to the circuit 70. The voltage of the cell 20 powers the voltage/resistance/temperature monitoring circuit 70 of Figure 12. The signal received from the cell voltage/resistance/temperature monitoring circuit 70 is converted in a converter 72 and passed on to an electronic circuit 74. The output of the electronic circuit 74 activates one of five voltage-to-frequency converters 76. These converters 76 prodsuce signals whose frequencies respectively measure the cell voltage (between points A and A'), the bus-to-cell connection resistancde (through voltages at B and B'), the cell resistance (through voltages at B and B' and at C and C'), and the cell temperature (through a volrtage from the temperature sensor T). The voltage-to-frequency converters 76 report sequentially under the control of circuit 74. whose function is to provide sequential reports of the signals A-A', B-B', C-C', H, and T so that a conventional external processor (not shown) may determine voltage, bus-cell connection resistance, cell resistance, cell current, and cell temperature. The voltages at points B and B' reflect the cell resistance, while the voltages at points C and C' do not, so by subtracting the C voltages from the B voltages, a measure of the cell reistance can be developed.

Figure 13 shows a circuit 90 for performing a cell internal resistance test. The test is performed by toggling a switch such as a field-effect transistor 94 with a pulse generator 92 so as to briefly discharge storage capacitor 96 through the cell20, which is supplying a current through a load resistor 97. The storage capacitor 96 is precharged by power supply 98 before

the pulse test is imposed on the cell 20. Voltages measured at points e, i, and g can be used to infer the internal resistance of the cell 20 by monitoring the voltage across the cell 20 bvetween points e and g, and monitoring the current through the cell 20 by measuring the voltage imposed across the calibrated resistor 99.

Figure 14A shows the response of a fully charged electrolytic storage cell 20 to the pulse charge test whose circuitry is shown in Figure 13. In this case, the internal resistance is determined to be 1.10 milliohms. The upper trace in Figure 14A represents the voltage between points e and g in Figure 13, while the lower trace represents the voltage between points i and g.

Figure 14B shows the results of a similar pulse charge test performed on an electrolytic storage cell 20 which has undergone a change in the quantity of charge available by 140 amp hours (10% beyond rated discharge capacity). In this case, the internal resistance has increased to 1.45 milliohms. The upper trace in Figure 14B represents the voltage between points e and g in Figure 13, while the lower trace represents the voltage between points i and g. Comparison of the upper traces in Figures 14A and 14B shows that the voltage between the points e and g has increased after the cell 20 has been discharged, while the lower trace has not changed. This indicates that the internal resistance of the cell 20 has increased. The amount of that increase can be obtained through a conventional analysis of the four voltages described above.

Figure 15 illustrates the electrolytic storage cell 20 with the multi-turn sense coil 50 which is electrically connected to a conventional monitoring module 60. The monitor module 60 contains sensors, signal conditioners, a DC-DC converter, a decoder, and telemetry. The monitoring module 60 can further measure the output voltage, resistance, temperature, electrolyte level, and state-of-charge of a battery storing electrical energy as described above.

Figure 16 illustrates a schematic diagram of one embodiment of the monitoring module 60. The monitoring module 60 includes a programmed single chip microcomputer 100, an input power supply 102 connected to the single chip microcomputer 100, and appropriate sensors 104. In addition, the single chip microcomputer 100 is connected to a conventional telemetry transmitter 106 which can, for example, communicate with the serial telemetry adaptor 95 shown in Figure 18. In addition, the single chip microcomputer 100 is connected to the telemetry receiver 108. As is clear from Figure 18, the

telemetry transmitter 106 and receiver 108 can be used to establish two-way communications between each individual sensor module 60 and the computer 96.

Figure 17 illustrates one embodiment of the present invention, whereby a plurality of individual electrolytic storage cells 20, connected together, in a series array by their terminals 24 and 26 to produce a relatively high voltage DC current source, are individually equipped with cell monitors 60.

Figure 18 illustrates a cell monitoring system according to the present invention. Each of a plurality of the individual electrolytic storage cells 20 has the monitoring module 60 attached. Each monitoring module 60 is capable of conventional two-way communications with a personal computer 97 by way of serial-to-telemetry adaptor 94. This personal computer 97, equivalent to an IBM XT or AT, serves as a central controller and processor for the entire array of electrolytic storage cells 20. If desired, all monitoring modules 60 can remain in an "off" or "standby" condition until each is queried one at a time in sequence by personal computer 97 which will, for each cell, issue an encoded command recognized only by the targeted cell monitor 60. When commanded, the targeted cell monitor 60 will respond by turning on, measuring all parameters, and sending data to personal computer 97. If desired, the computer 97 can issue commands to the serial-to-telemetry adaptor 94, which, in turn, sends appropriate signals to the identified electrolytic storage cell 20.

In addition to performing such tasks directed toward monitoring the electrical parameters of the electrolytic storage cells 20, the cell monitoring function also determines the onset of the evolution of bubbles of gaseous hydrogen in the electrolyte acoustically (through, conventional miniaturized microphones, for example). The function can also maintain automatic cell charge balance among the operating cells 20. This is accomplished by reducing the voltage on those cells 20 whose output voltage is high while increasing the voltage on those cells whose output voltage is low. Such adjustments in cell voltages can be accomplished by adjusting the state-of-charge of each of the cells 20.

An additional cell monitoring function provided by the monitoring module 60 is fluid level maintenance to automatically add water or other electrolytes (through conventional means, which have been automated) to the affected electrolytic storage cell 20. Such fluids may be lost from the cell 20 by

evaporation or by being expended during the operation of the cell. A final cell monitoring function is to monitor sediment level in the enclosure 22 of the electrolytic storage cell 20 using SONAR or other conventional principles to measure the thickness of the sediment layer.

While it is clear that those skilled in the art can make various modifications of the embodiments disclosed above, the invention is to be limited only by the following claims.

WD80-6V1

Claims

1. A system for monitoring electrolytic parameters of one or more electrolytic storage cells, comprising :

a monitoring module associated with each storage cell, each monitoring module having:

a. one or more sensors attached to the enclosure of the associated storage cell,

b. means for measuring the complex impedance of each of the attached sensors, the complex impedance being a function of the electrolytic parameters of the associated storage cell, and

c. means for producing signals representative of the electrolytic parameters of the associated storage cell;

means for addressing each monitoring module to collect the signals representative of the electrolytic condition of each storage cell; and

means for processing the collected signals to monitor the condition of each storage cell.

2. The system of claim 1 wherein the one or more sensors include a sensor for detecting the level of an electrolyte in the associated storage cell.

3. The system of claim 2 wherein the sensor for detecting the level of an electrolyte in the associated storage cell includes a plurality of capacitive sensors.

4. The system of claim 2 wherein the sensor for detecting the level of an electrolyte in the associated storage cell includes an inductive coil.

5. The system of claim 1 wherein the one or more sensors includes a sensor for detecting the specific gravity of an electrolyte in the associated storage cell.

6. The system of claim 1 wherein the one or more sensors includes a sensor for detecting the state-of-charge of the associated storage cell.

7. The system of claim 1 wherein the one or more sensors includes a circuit for measuring the voltage, the internal resistance, the temperature, the resistance of the external connections, and the current passing through the associated storage cell.

8. A system for monitoring electrolytic parameters of one or more electrolytic storage cells, comprising:

a monitoring module attached to each storage cell, each monitoring module having:

a. means for generating a signal containing a predetermined frequency,

b. coupling means for coupling the signal into each storage cell,

c. a sensor attached to the associated storage cell,

d. means for measuring the complex impedance of the sensor at the predetermined frequency, the complex impedance being a function of the electrolytic parameters of the associated storage cell, and

e. means for producing signals representative of the electrolytic parameters of the associated storage cell;

means for addressing each monitoring module to collect the signals representative of the electrolytic condition of each storage cell; and

means for processing the collected signals to monitor the condition of each storage cell.

9. The system of claim 8 wherein the means for measuring the complex impedance of the sensor is an inductive means attached to the enclosure of the associated storage cell.

10. The system of claim 7 wherein the monitoring module further includes means for sensing the specific gravity of the associated storage cell.

11. The system of claim 7 wherein the monitoring module further comprises means for sensing the state-of-charge of the associated storage cell.

12. The system of claim 11 wherein the state-of-charge sensing means includes a multi-turn planar coil lying substantially in a horizontal plane that intersects the electrolyte of the associated storage cell below its surface.

13. The system of claim 11 wherein the state-of-charge sensing means comprises means for generating a charge pulse, means for applying the charge pulse to the associated storage cell, and means for generating a signal indicating the response of the associated storage cell to the charge pulse.

14. A system for monitoring electrolytic parameters of one or more electrolytic storage cells, comprising:

a monitoring module attached to each storage cell, each monitoring module having:

a. means for generating a signal containing a predetermined frequency,

b. coupling means for coupling the signal into each storage cell,

c. a sensor attached to the associated storage cell,

d. means for measuring the complex impedance of the sensor at the predetermined frequency, the complex impedance being a function of the electrolytic parameters of the associated storage cell,

e. means for producing signals representative of the electrolytic parameters of the associated storage cell;

f. communication means for transmitting and receiving signals; and

g. a microprocessor operating under the control of a program to send the signals representative of the electrolytic parameters of the associated storage cell to the communication means and to receive command signals from the communication means;

means for addressing each monitoring module to collect the signals representative of the electrolytic condition of each storage cell and to transmit the command signals to the addressed monitoring module; and

means for processing the collected signals to monitor the condition of each storage cell and generating the command signals in response to the condition of each storage cell.

15. The system of claim 14 wherein the means for processing the signals is a programmed computer.

16. A system for maintaining an array of one or more electrolytic storage cells at a desired state, comprising:

a. means for adding or withdrawing charge to maintain state-of-charge uniformity between all cells, and

b. means for replacing evaporated or expended fluids to mainmtain electrolyte uniformity betwen all cells.

17. The system of claim 14 wherein the means for monitoring the state of each storage cell includes means for measuring the evolution of by-products produced from charging the storage cell.

18. The system of claim 15 wherein the storage cell is a lead-acid cell and one of the by-products measured by the means for measuring the evolution of by-products is gaseous hydrogen.

19. The system of claim 16 wherein the means for measuring the evolution of by-products includes an acoustic sensor operable to detect bubble onset of gaseous hydrogen.

20. The system of claim 16 wherein the means for monitoring the evolution of by-products includes a sensor responsive to the presence of gaseous hydrogen.

21. The system of claim 14 wherein the means for monitoring the state of each storage cell includes means for measuring the level of sediment at the bottom of the enclosure of the storage cell.

22. The system of claim 14 wherein the means for causing the array of storage cells to be brought to a desired state includes means for adjusting a level of the electrolyte in each storage cell in the array of storage cells.

23. The system of claim 14 wherein the means for causing the array of storage cells to be brought to a desired state includes means for balancing the state-of-charge of each storage cell in the array of storage cells.

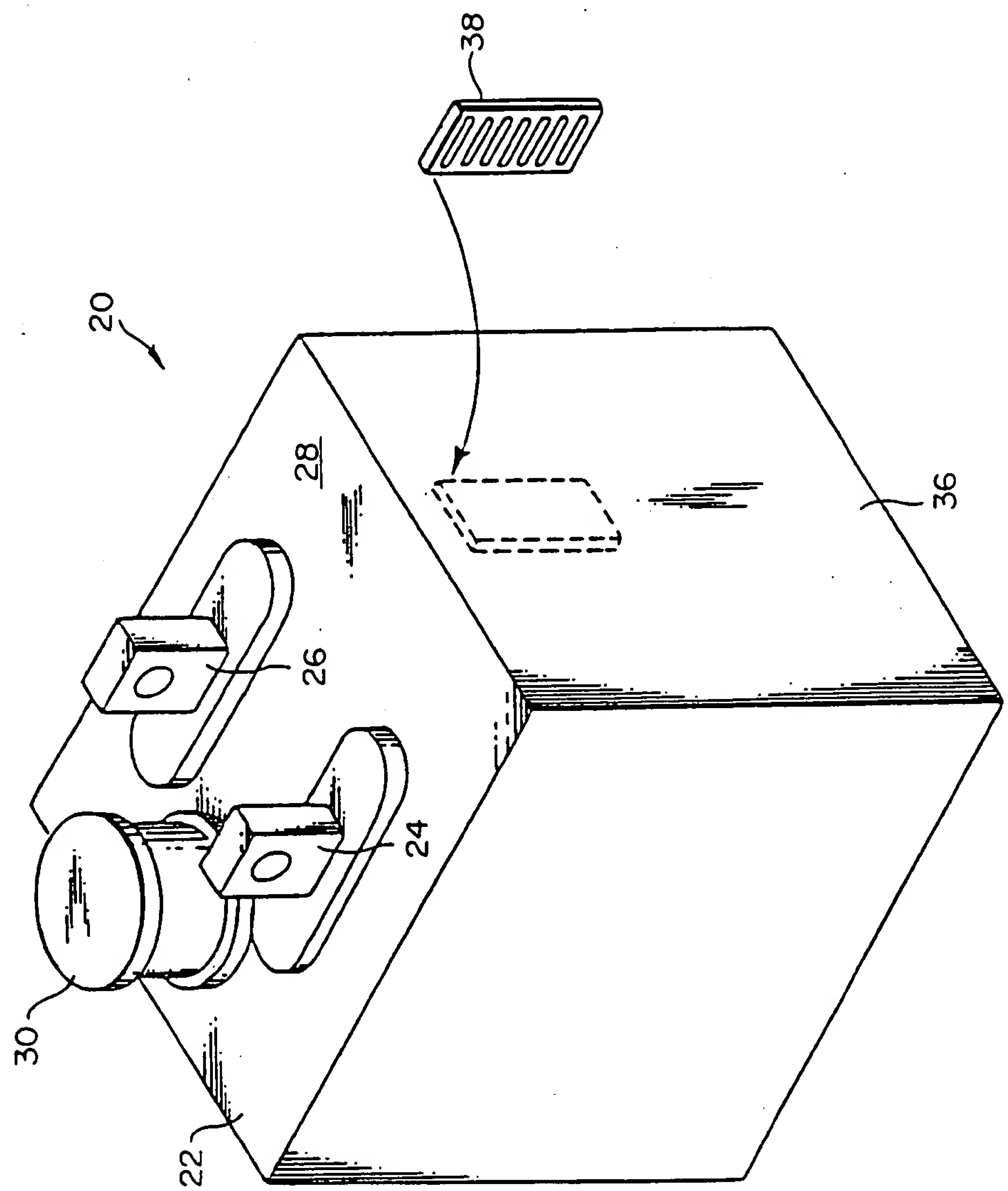


FIG. 1

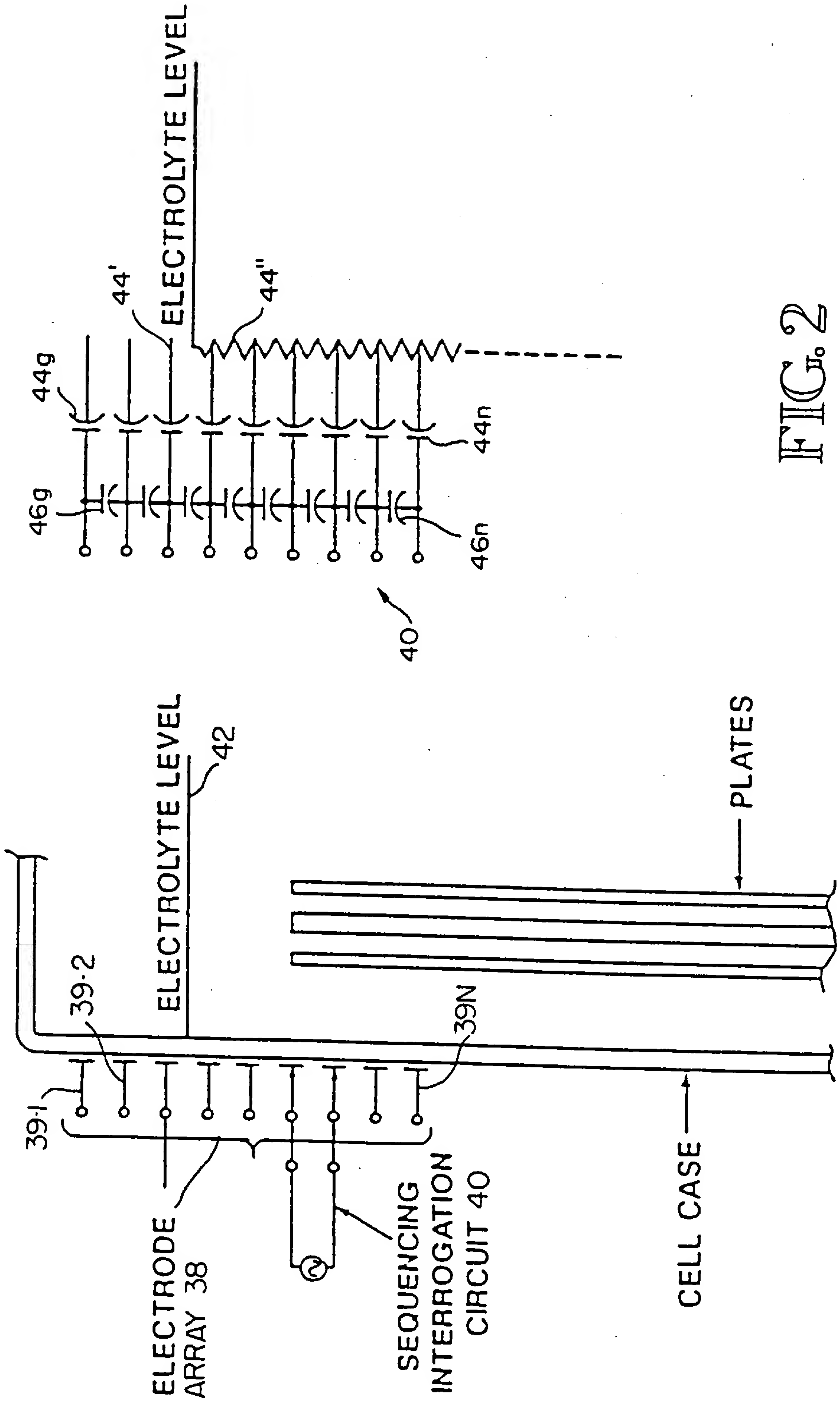
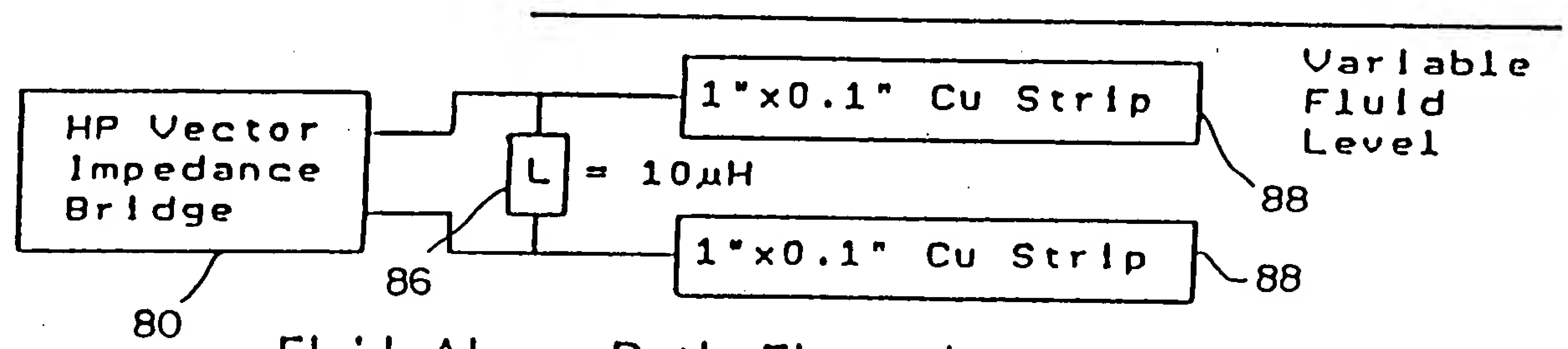

ELECTROLYTE LEVEL
44'
44"
44g
44n
46g
46n
40
ELECTROLYTE LEVEL
42
PLATES
39·2
39·1
39N
ELECTRODE ARRAY 38
SEQUENCING INTERROGATION CIRCUIT 40
CELL CASE

FIG. 2



Fluid Above Both Electrodes:

Resonant Frequency = 25.9 MHz
Resonant Impedance = 59 KΩ

Fluid Below Both Electrodes:

Resonant Frequency = 26.5 MHz
Resonant Impedance = 25 KΩ

Note:

If cell is tipped to place fluid level below electrodes, 15 minutes of evaporation time is required for Z to stabilize to 25 KΩ.

FIG.3

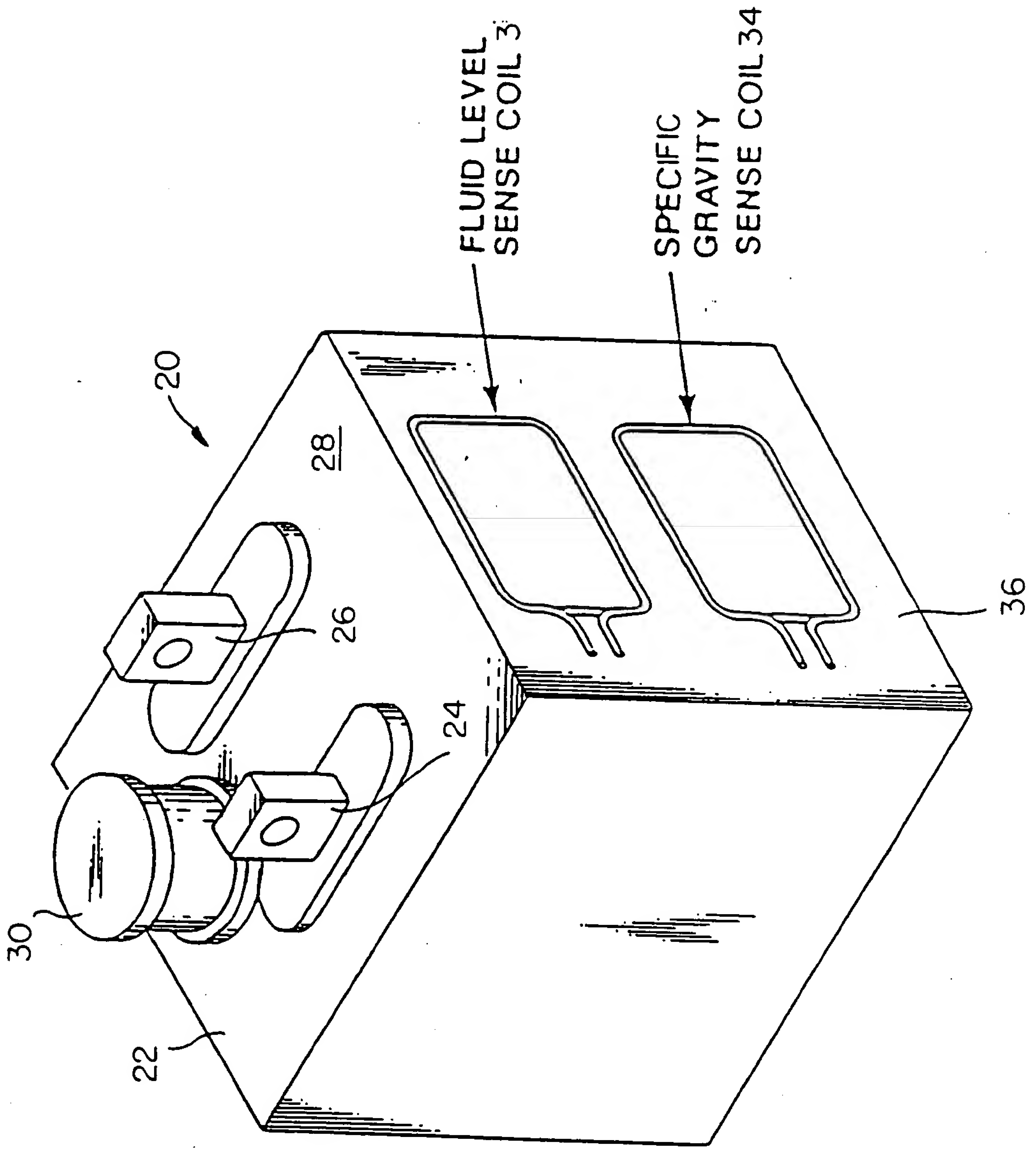
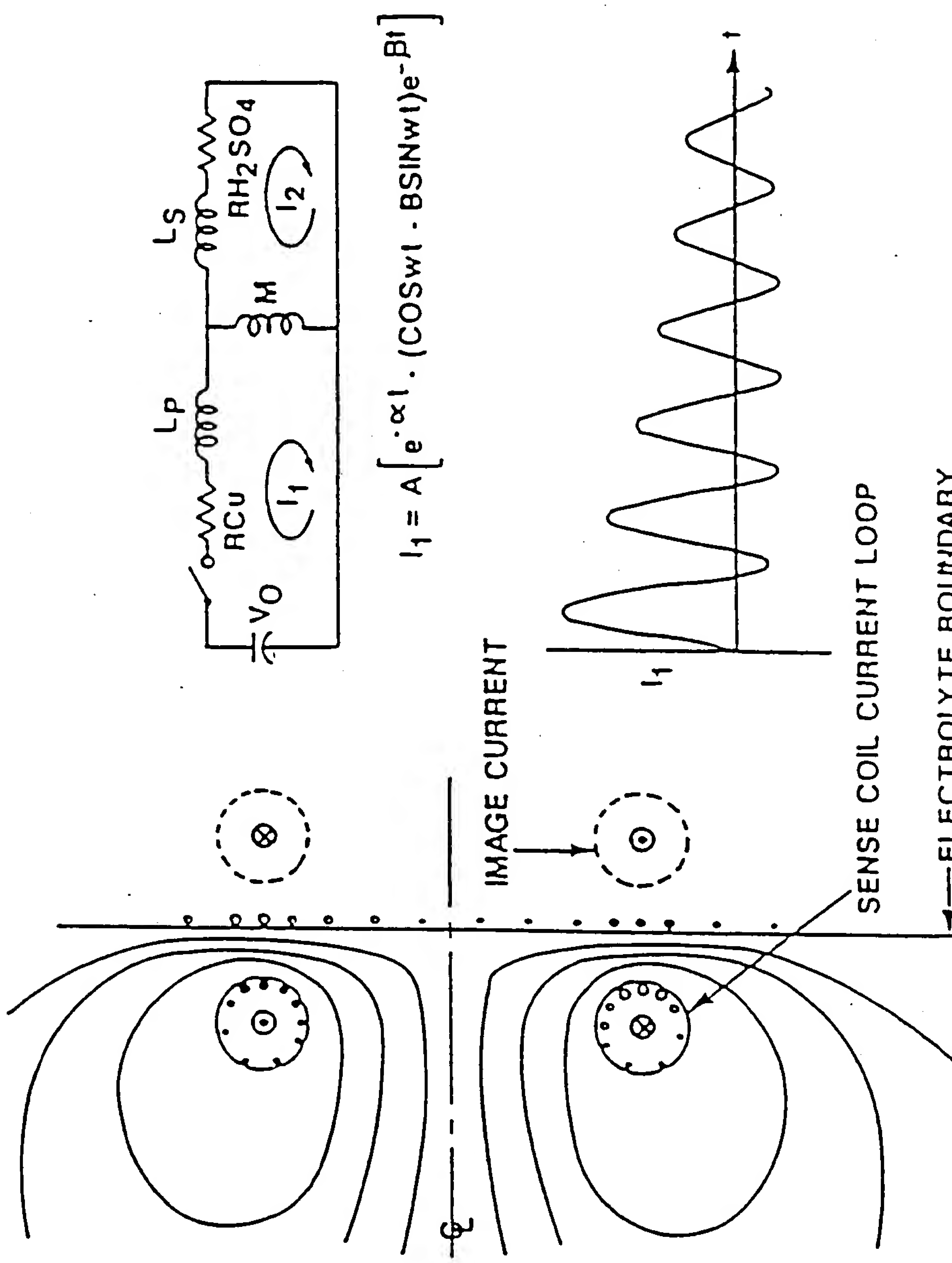
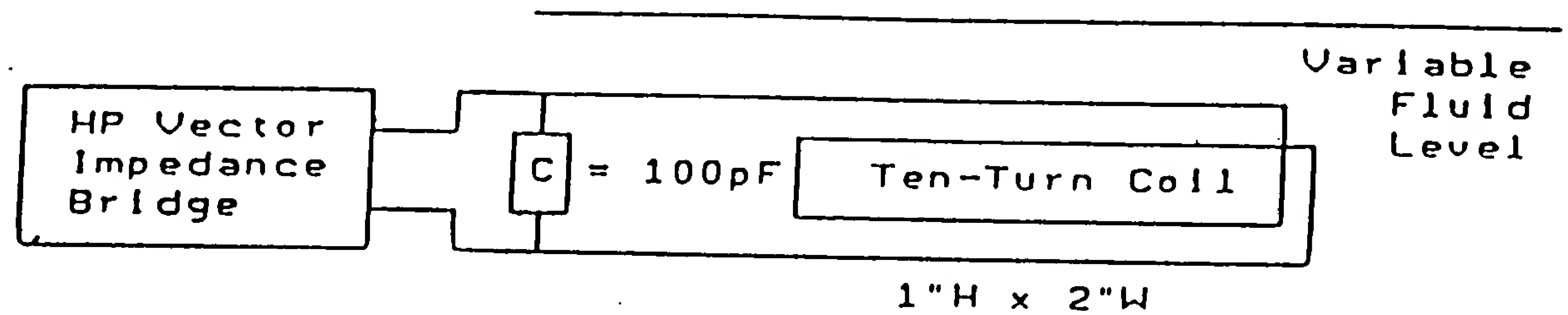

FLUID LEVEL
SENSE COIL 3
SPECIFIC
GRAVITY
SENSE COIL 34
20
28
26
24
30
22
36

FIG. 4



L_S
RH_2SO_4
I_2
M
L_P
RCu
I_1
V_O
$I_1 = A\left[e^{-\alpha t} \cdot (COS\omega t - BSIN\omega t)e^{-\beta t}\right]$
t
I_1
IMAGE CURRENT
SENSE COIL CURRENT LOOP
ELECTROLYTE BOUNDARY
℄

FIG. 5



Fluid Above Both Electrodes:

Resonant Frequency = 6.3 MHz

Resonant Impedance = 7.6 KΩ

Fluid Below Both Electrodes:

Resonant Frequency = 6.1 MHz

Resonant Impedance = 22 KΩ

Note:

If cell is tipped to place fluid level below electrodes, no noticeable delay is required to stabilize Z.

FIG.6

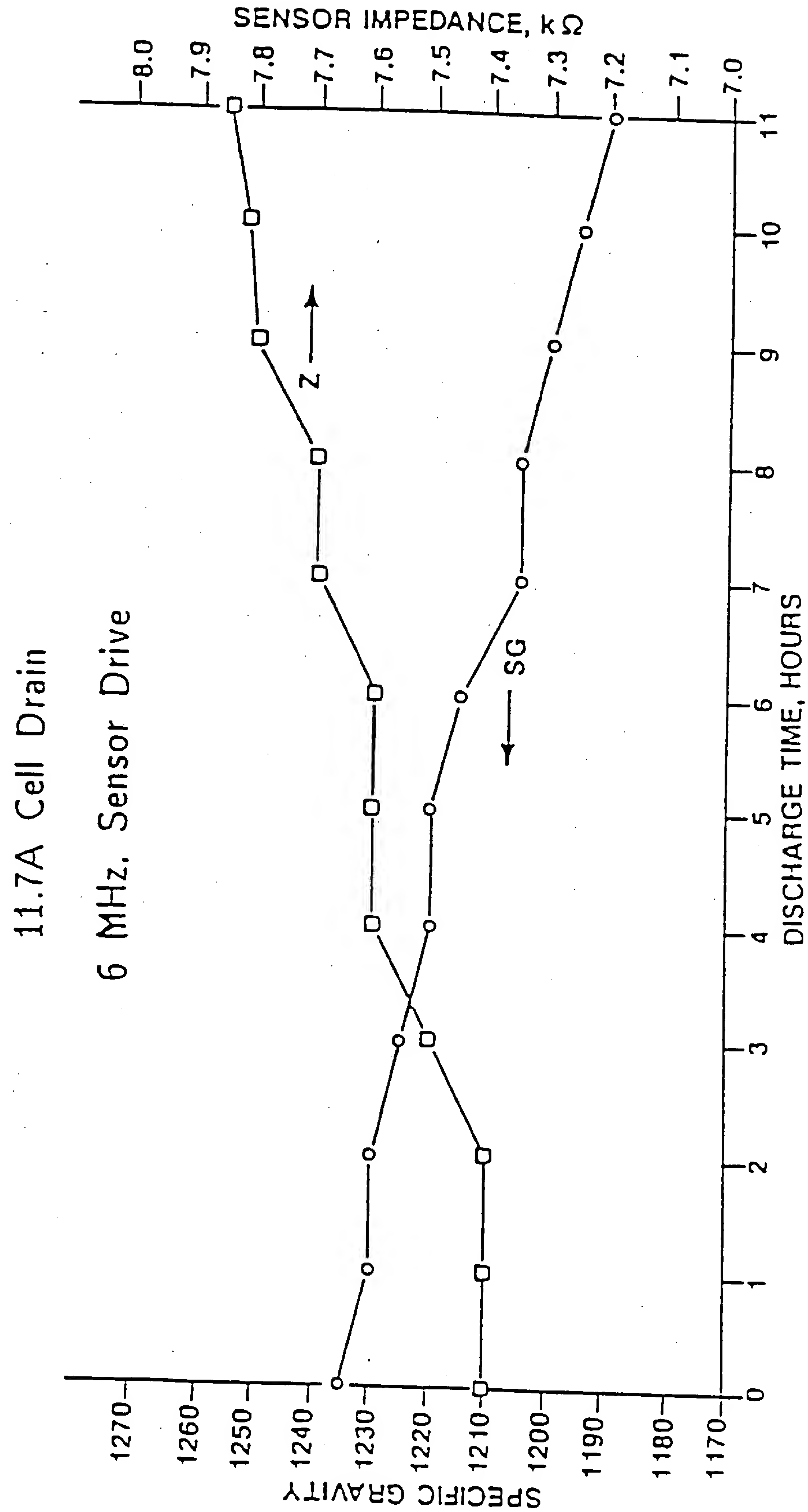

11.7A Cell Drain
6 MHz, Sensor Drive
SENSOR IMPEDANCE, kΩ
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
Z
SG
SPECIFIC GRAVITY
1270
1260
1250
1240
1230
1220
1210
1200
1190
1180
1170
DISCHARGE TIME, HOURS
0
1
2
3
4
5
6
7
8
9
10
11

FIG. 7

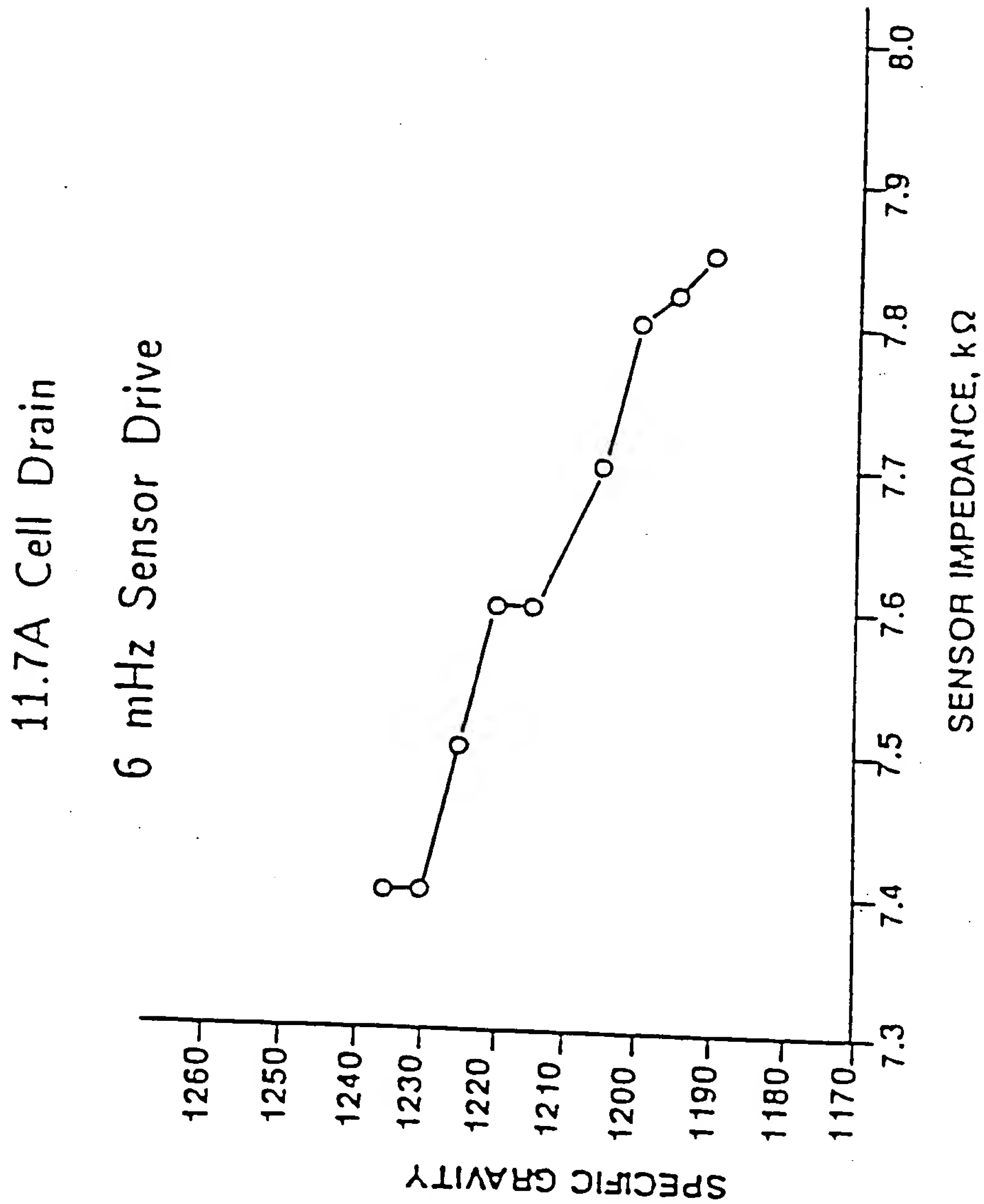

11.7A Cell Drain
6 mHz Sensor Drive
SPECIFIC GRAVITY
1170
1180
1190
1200
1210
1220
1230
1240
1250
1260
SENSOR IMPEDANCE, kΩ
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8.0

FIG. 8

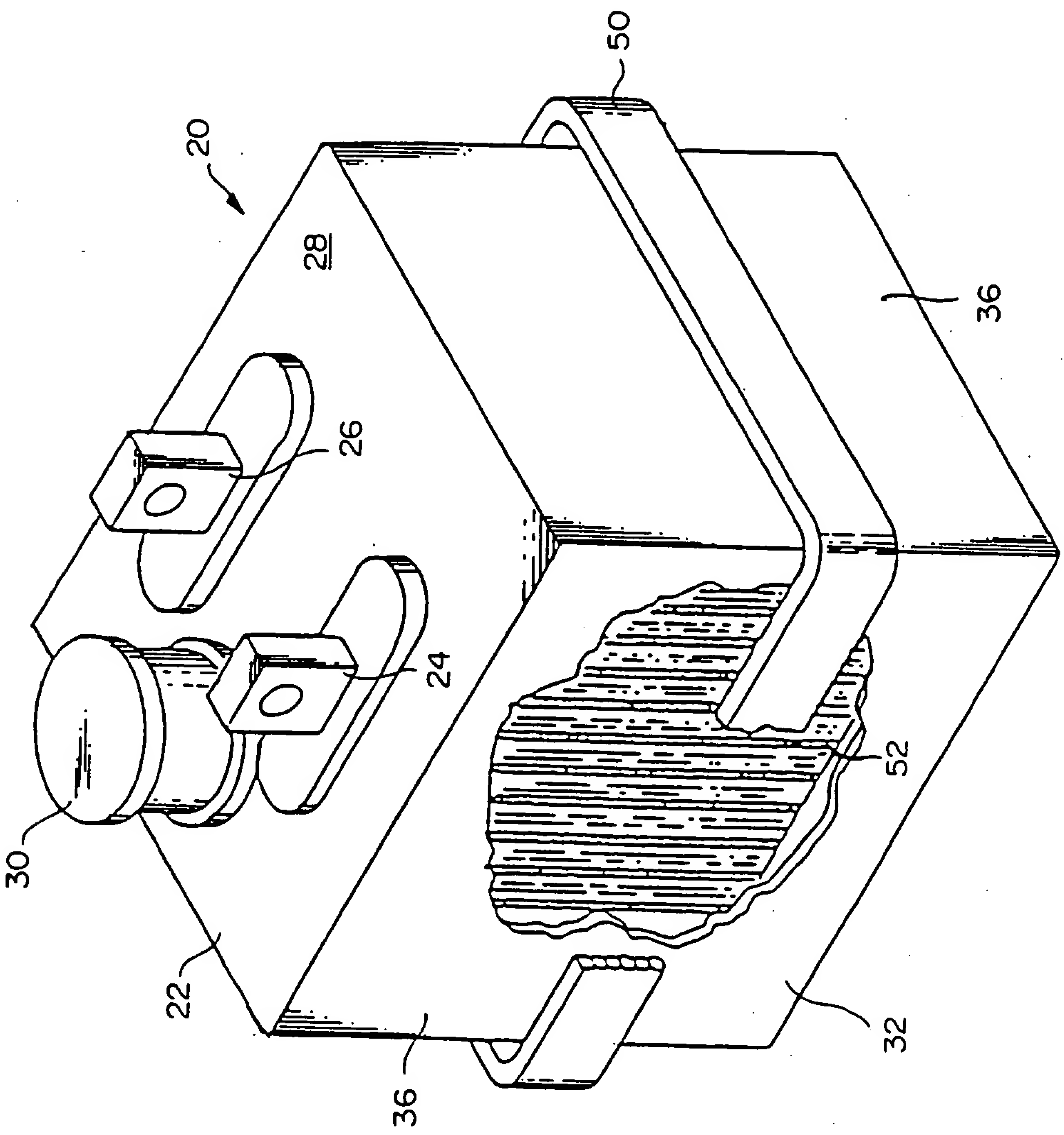


FIG. 9

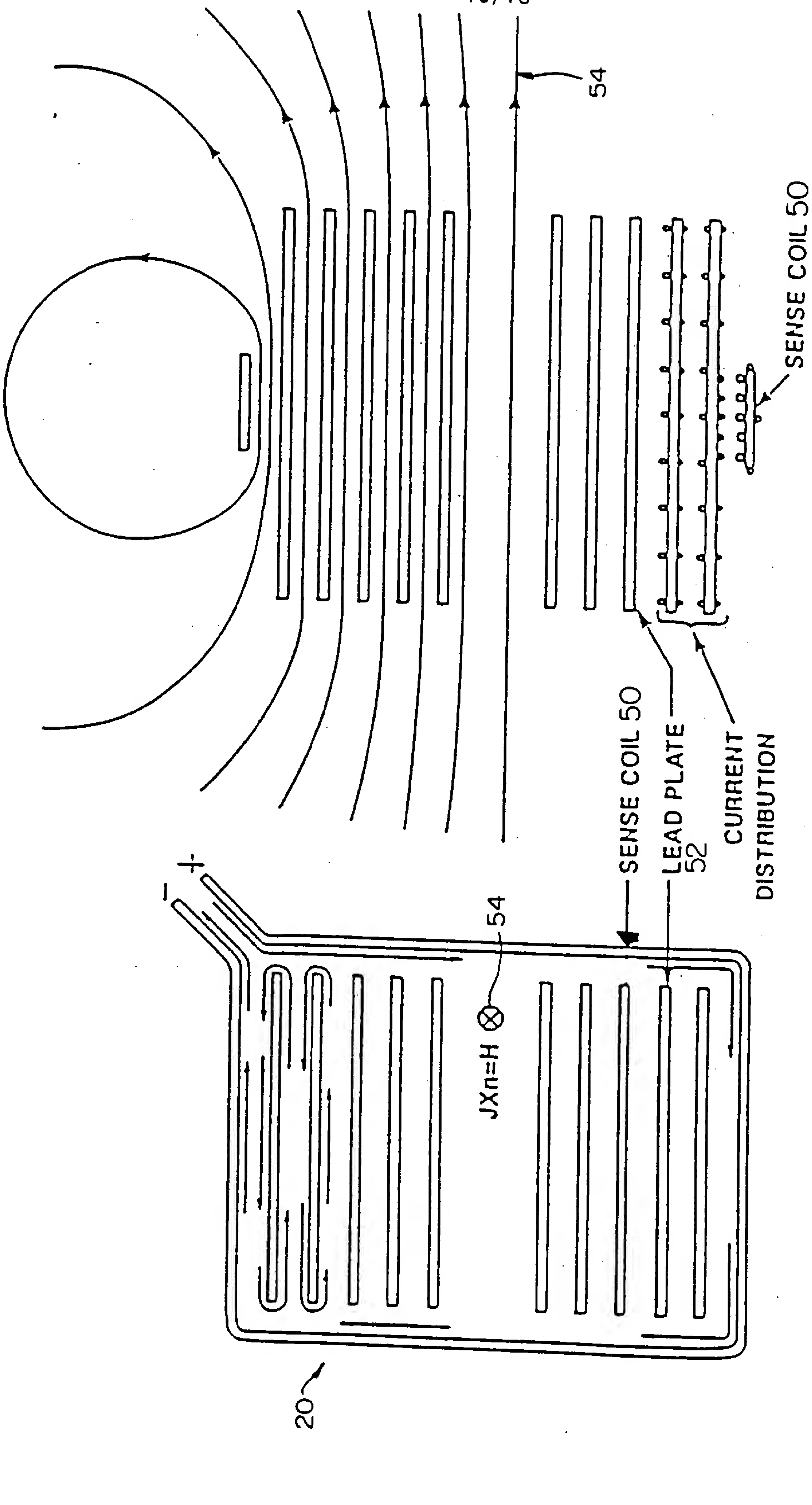

54
SENSE COIL 50
SENSE COIL 50
LEAD PLATE 52
CURRENT DISTRIBUTION
JXn=H
54
-
+
20

FIG. 10

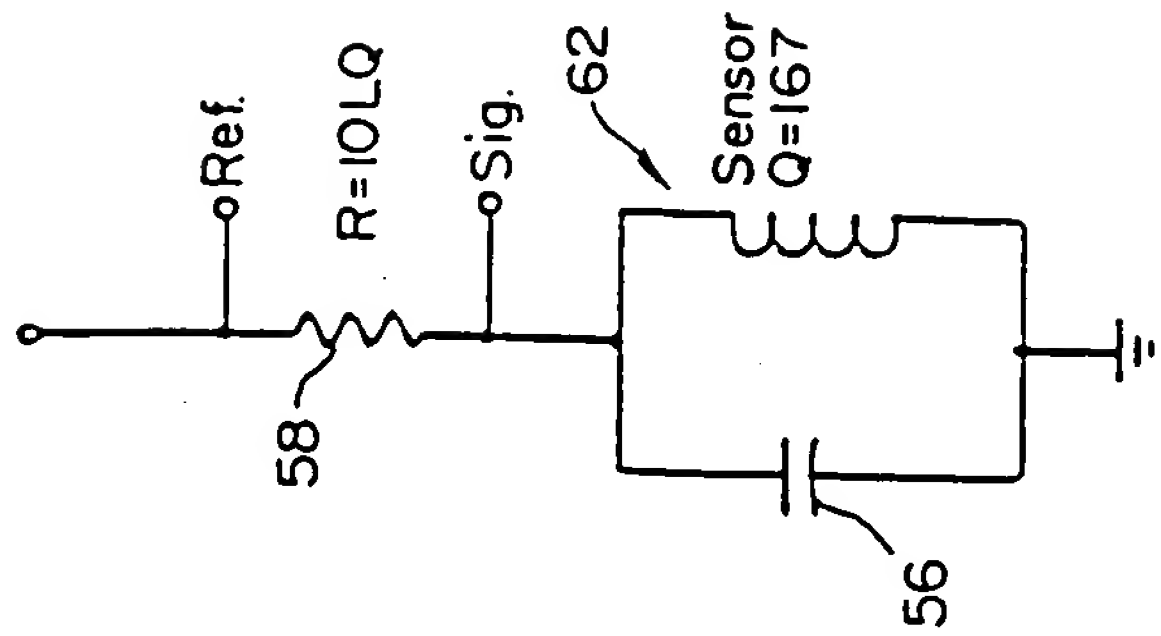


FIG. 11B

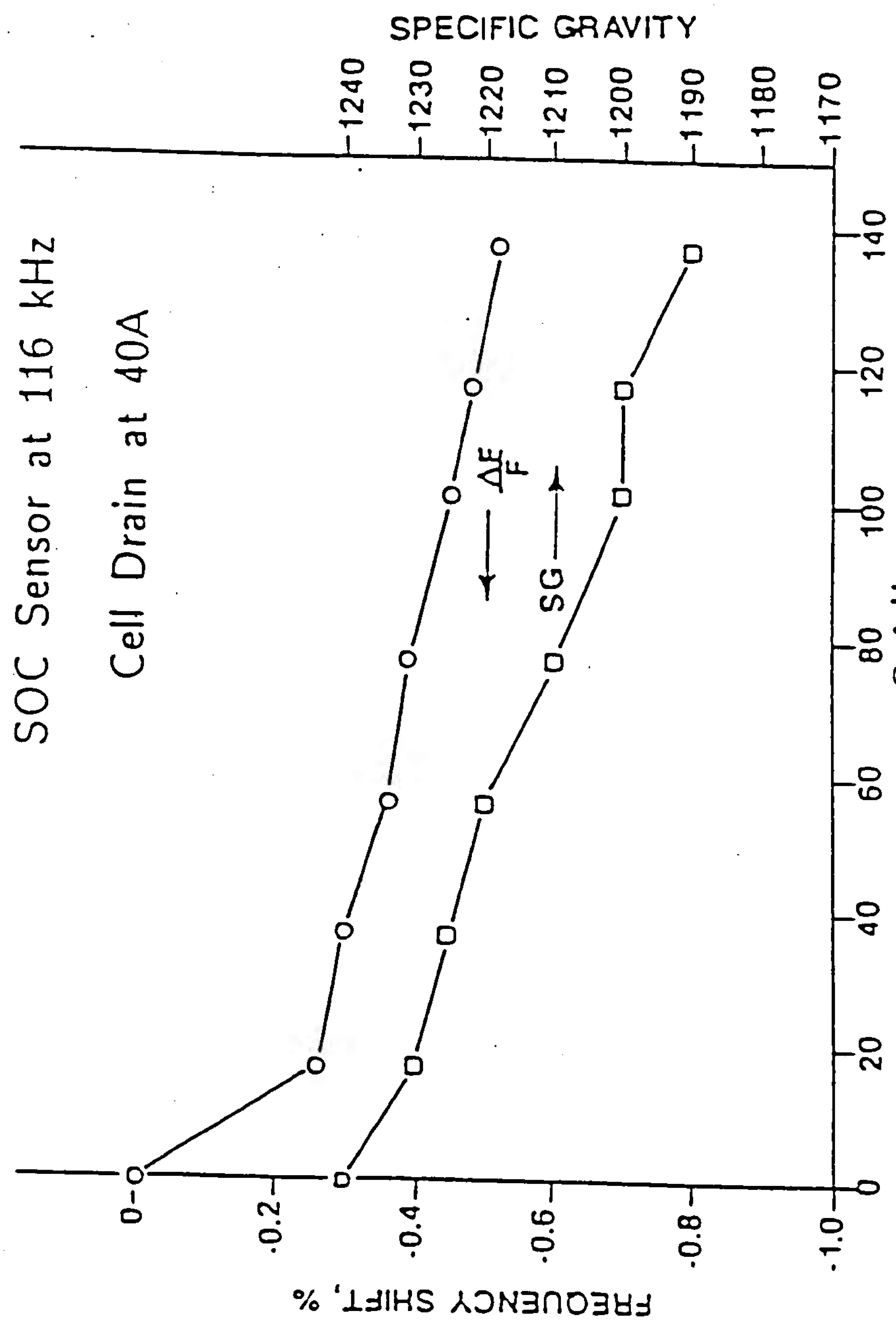
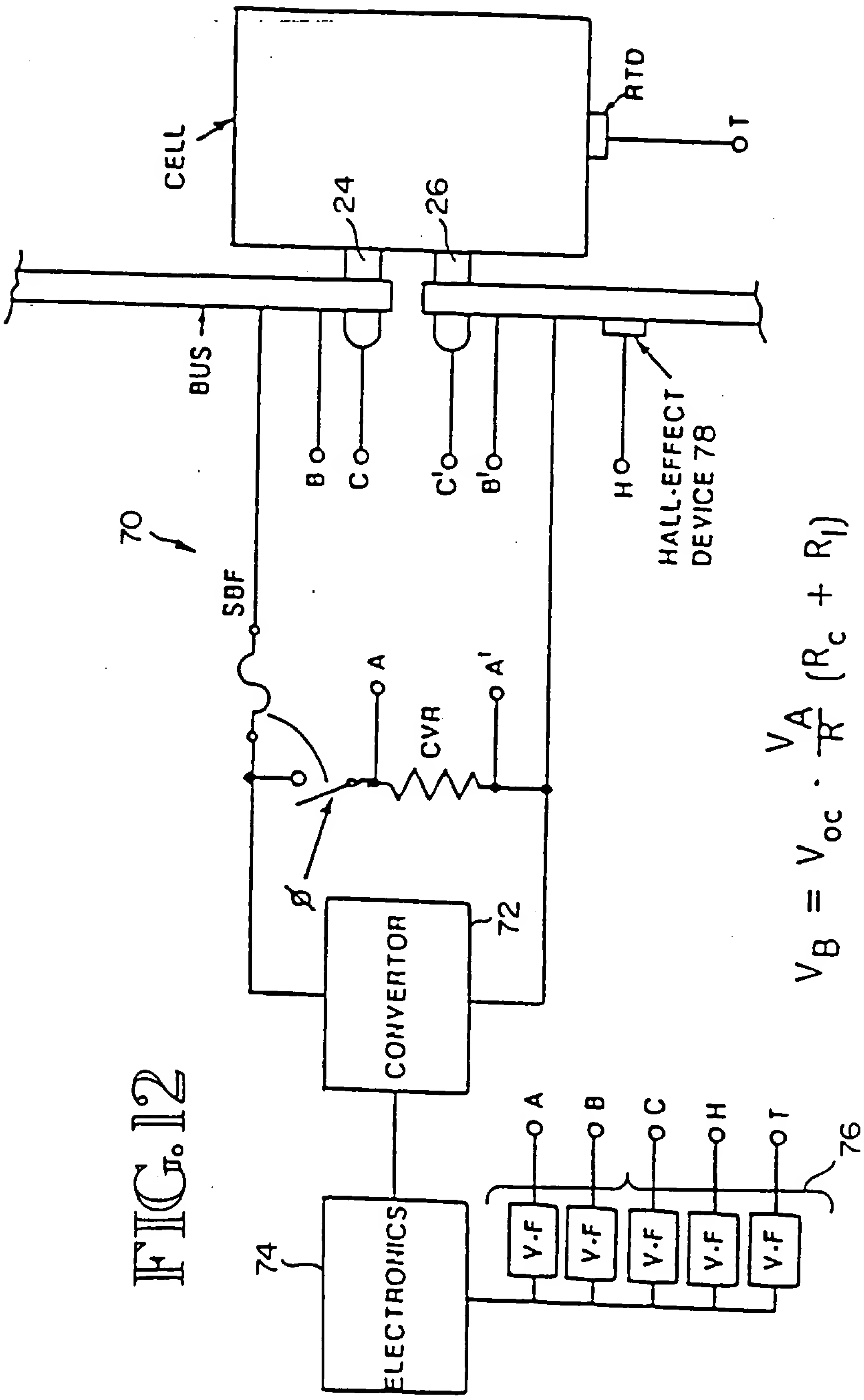


FIG. 11A



$$V_B = V_{oc} \cdot \frac{V_A}{R} (R_c + R_I)$$

$$V_C = V_{oc} \cdot \frac{V_A}{R} (R_I)$$

FIG. 12

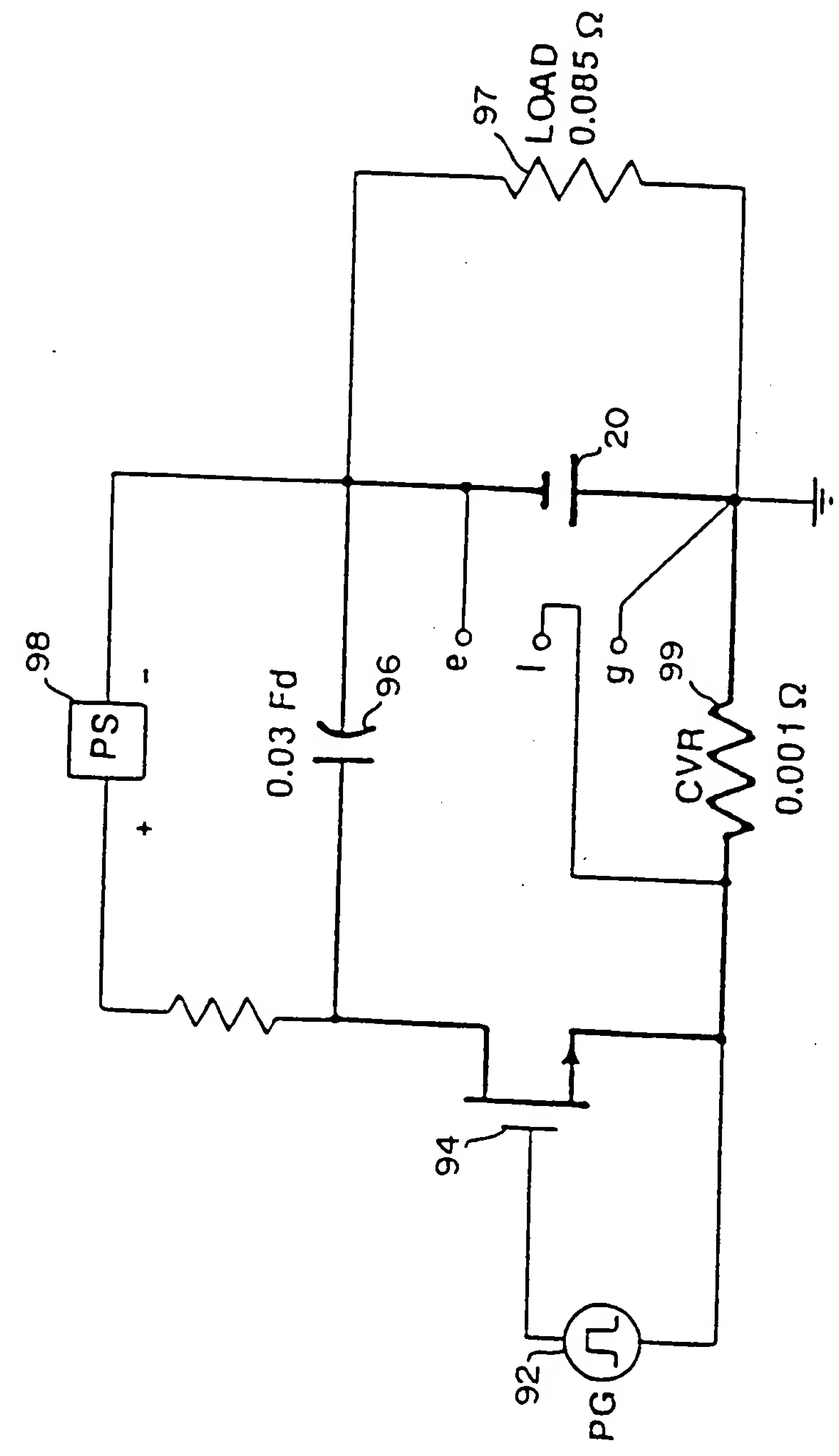


FIG. 13

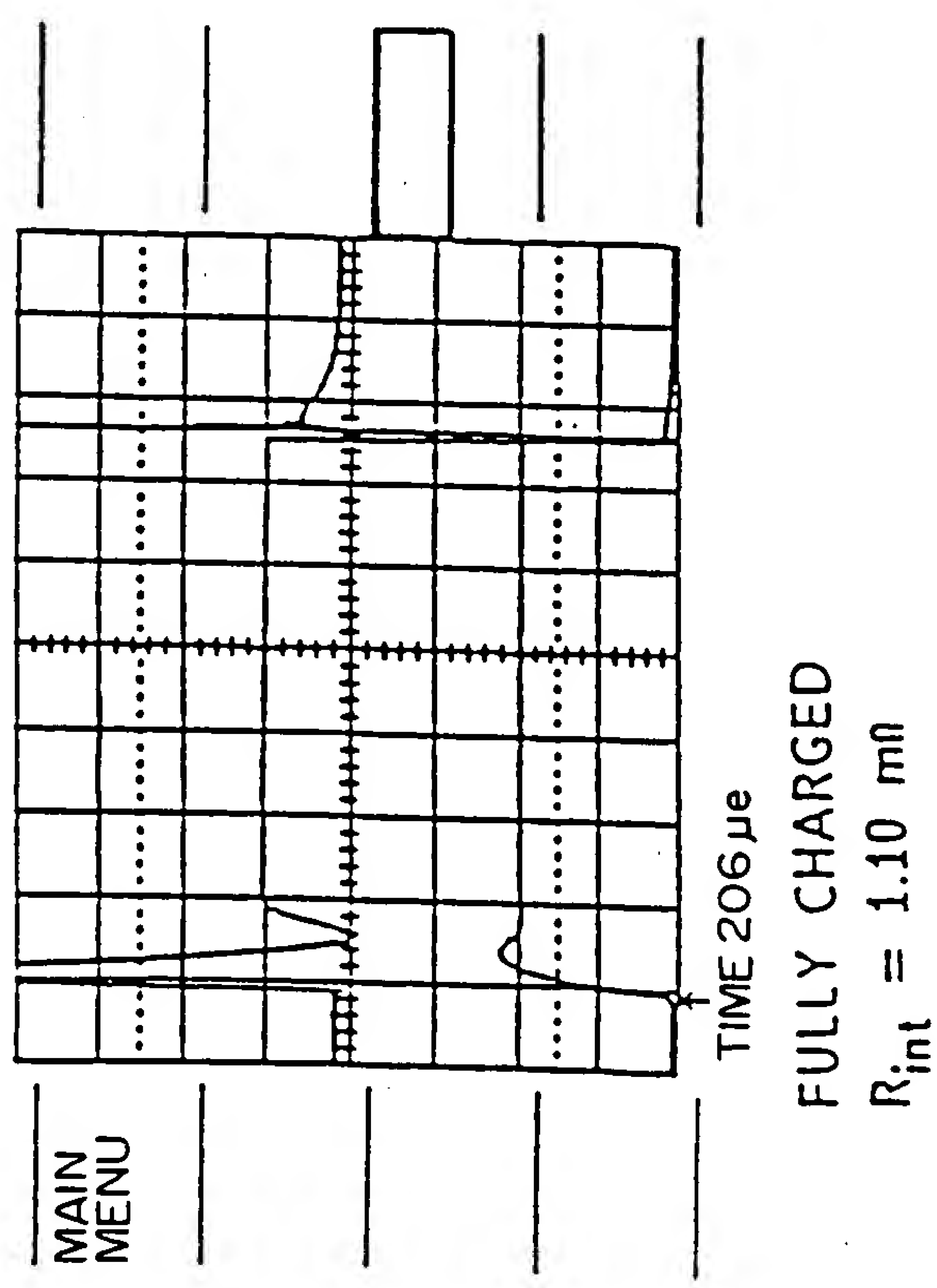


FIG. 14A

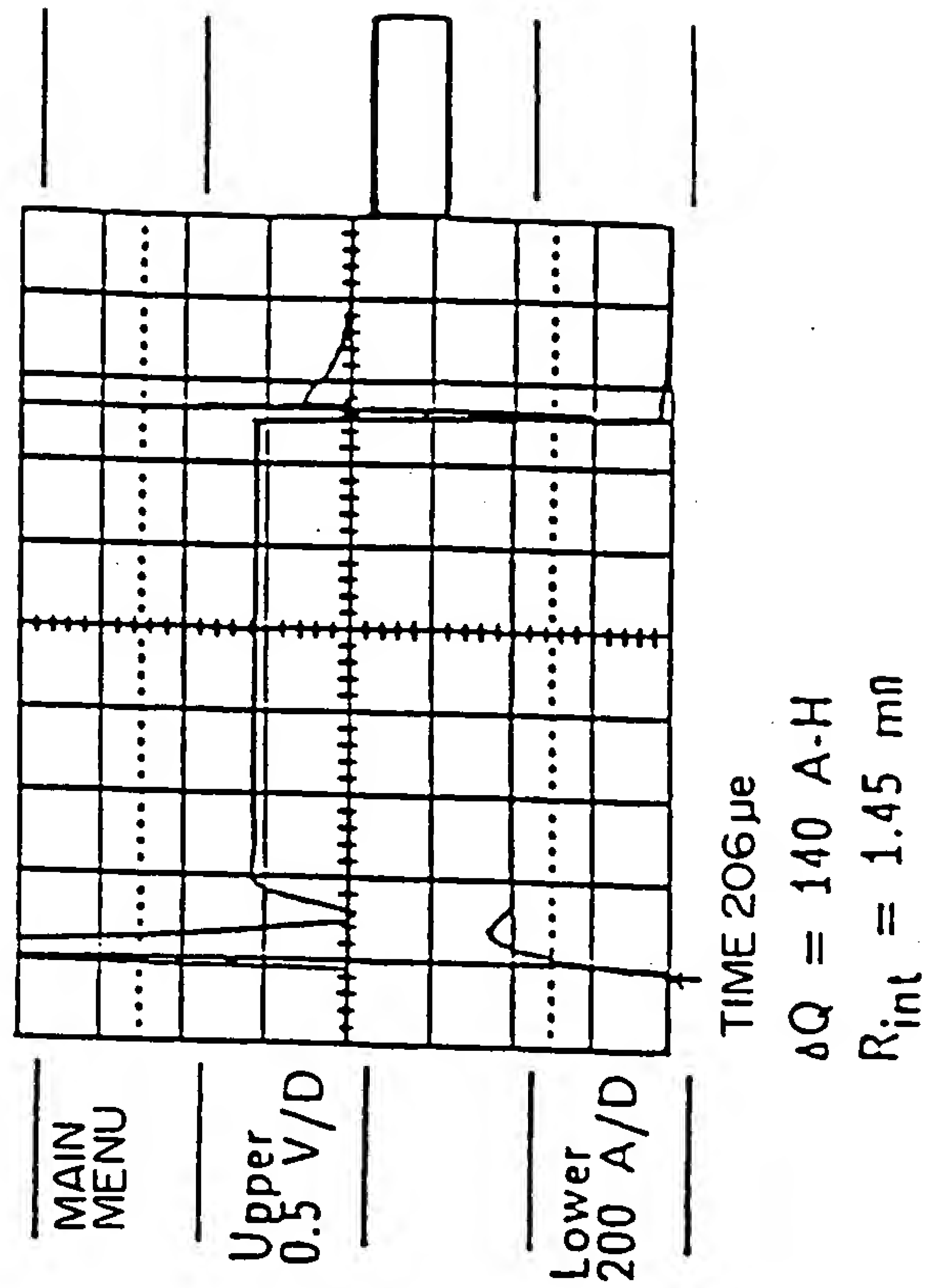
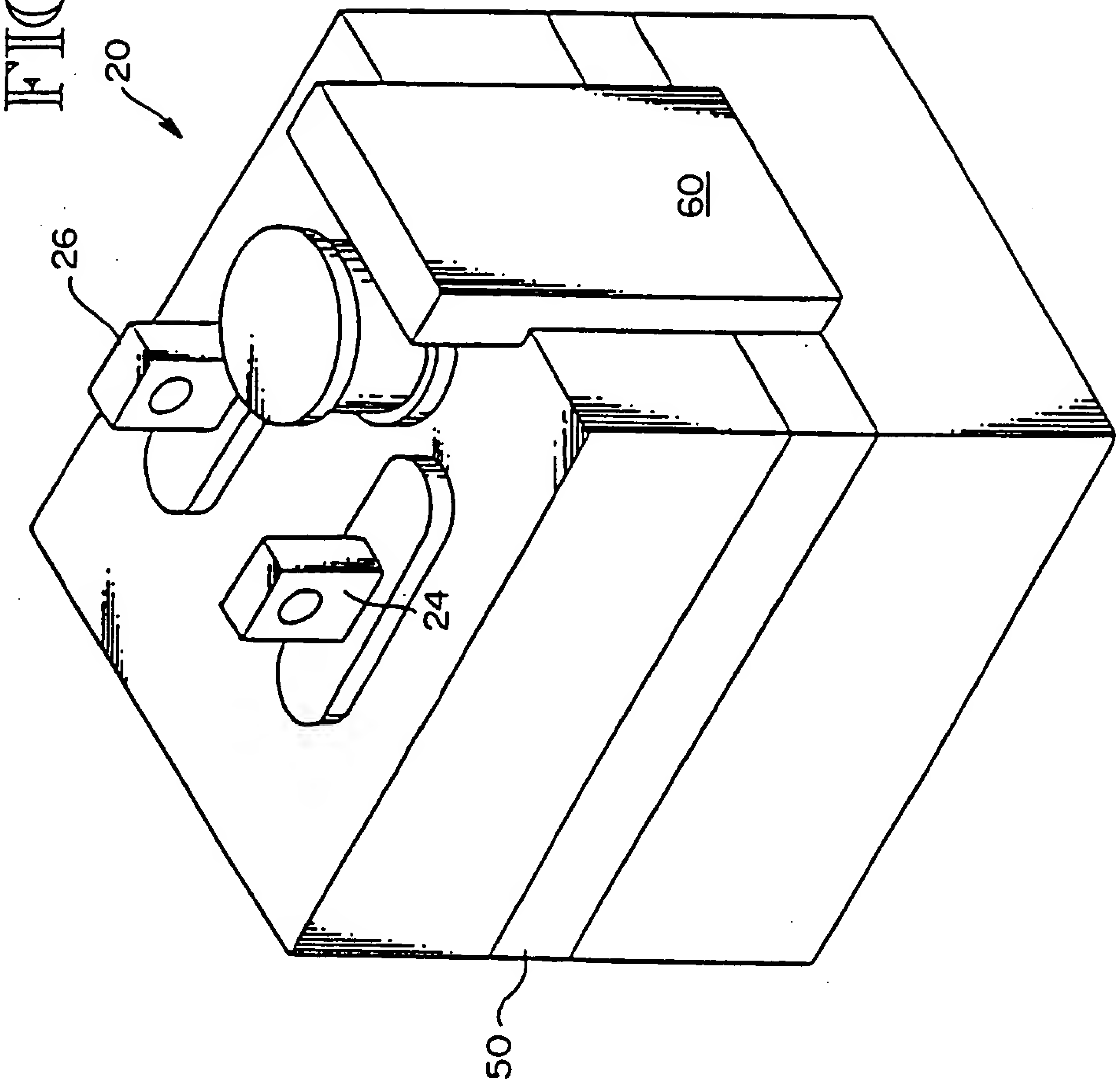


FIG. 14B

FIG. 15



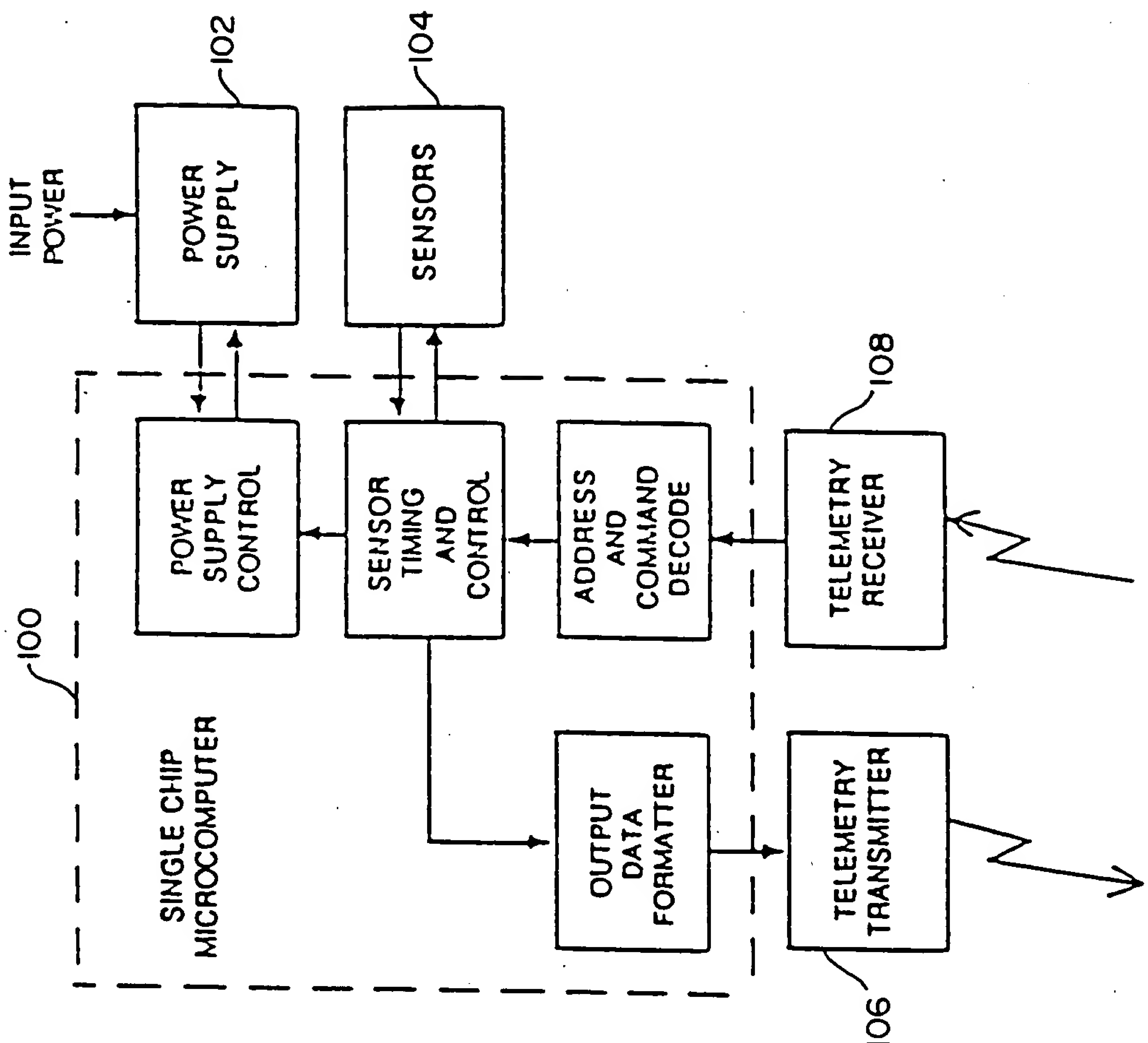

INPUT POWER
POWER SUPPLY
102
SENSORS
104
POWER SUPPLY CONTROL
SENSOR TIMING AND CONTROL
ADDRESS AND COMMAND DECODE
TELEMETRY RECEIVER
108
100
SINGLE CHIP MICROCOMPUTER
OUTPUT DATA FORMATTER
TELEMETRY TRANSMITTER
106

FIG. 16

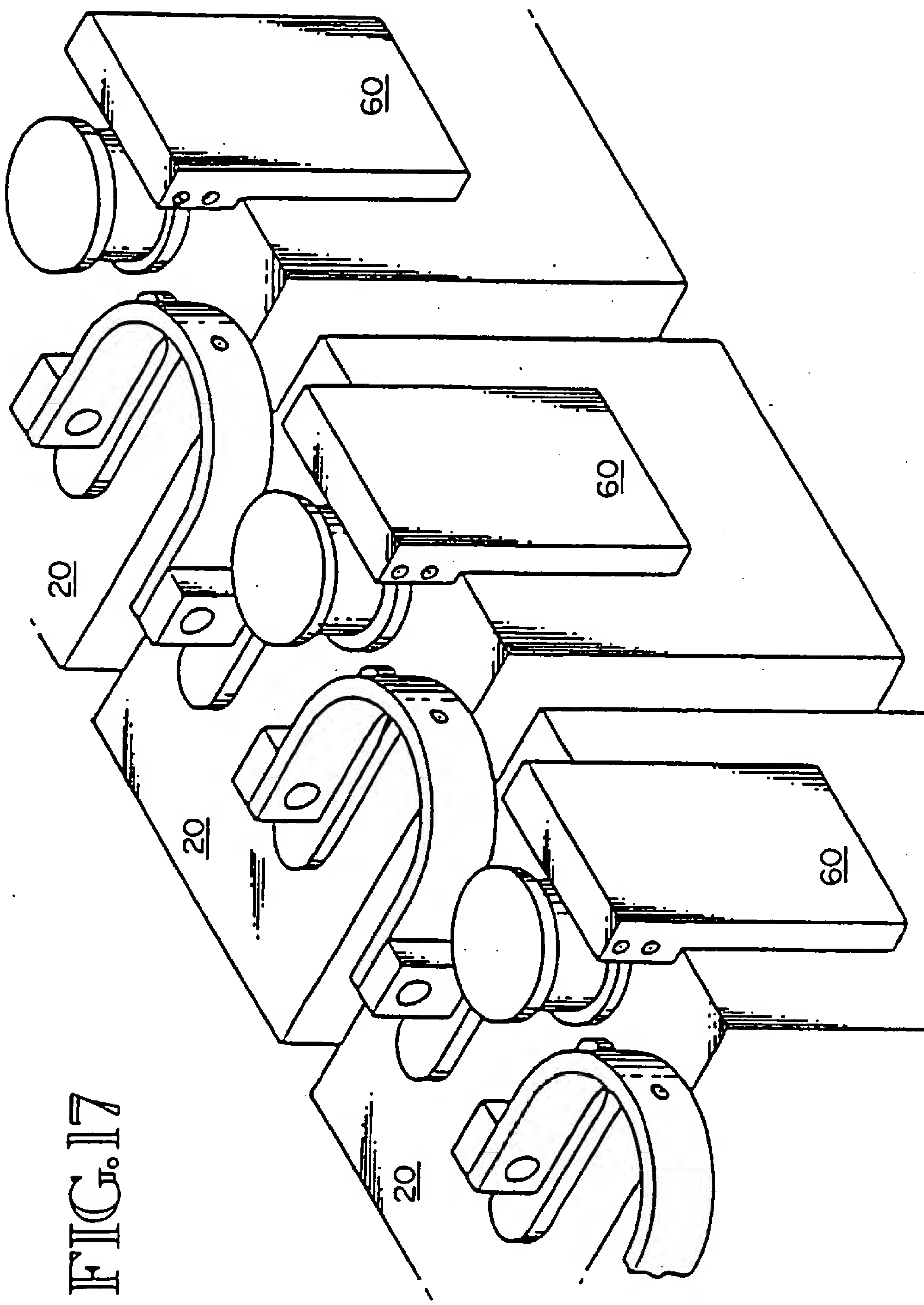


FIG. 17

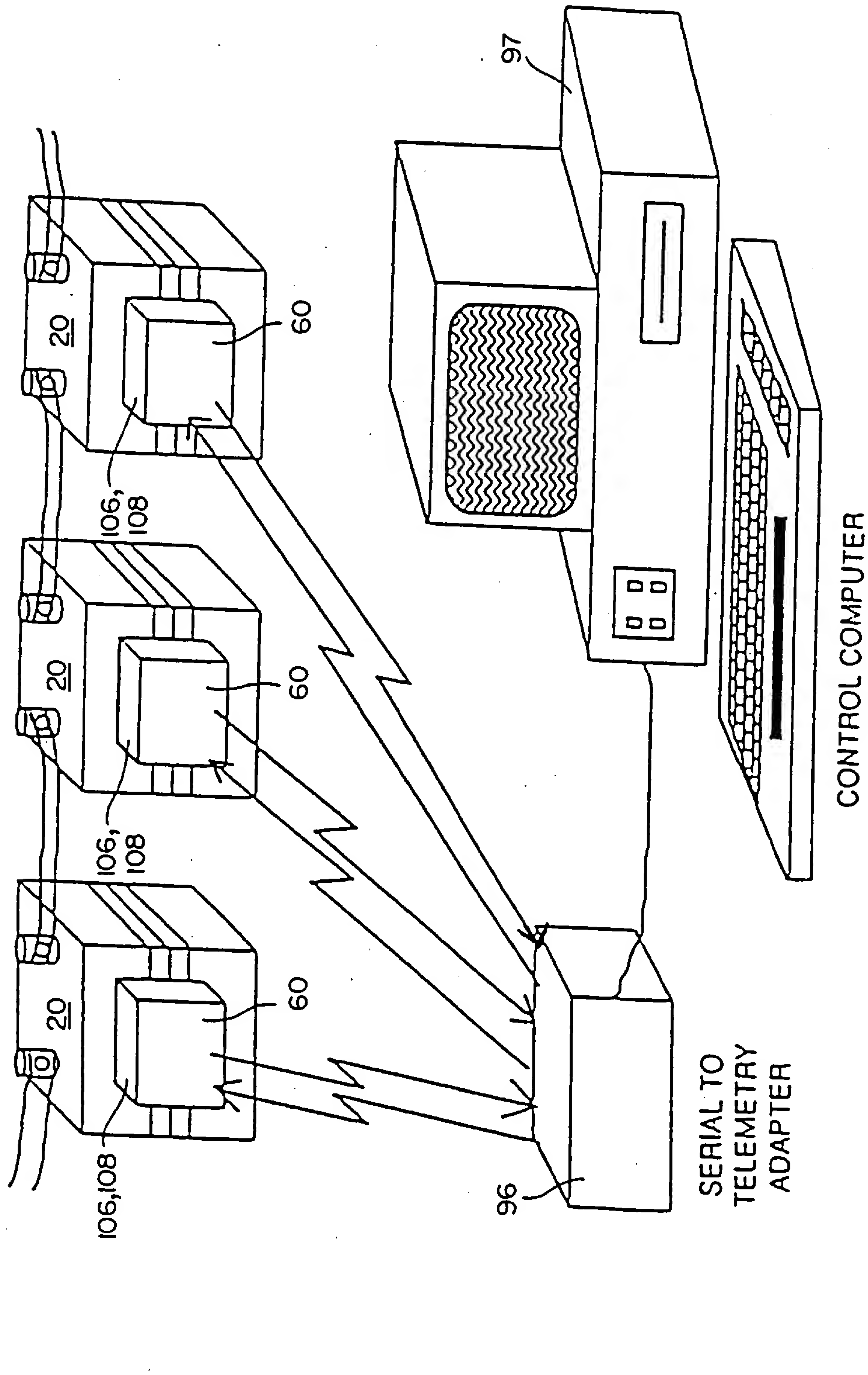

97
20
60
106,
108
20
60
106,
108
20
60
106,108
96
SERIAL TO
TELEMETRY
ADAPTER
CONTROL COMPUTER

FIG. 18

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/03052

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: H 01 M 10/48

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	H 01 M

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	Patent Abstracts of Japan, vol. 11, no. 312 (E-548)(2759), 12 October 1987 & JP, A, 62-105377 (TOKAI TRW KK) 15 May 1987 --	1,8
A	Journal of Power Sources, vol. 17, 1986 Elsevier Sequoia (NL) M. Hughes et al. "The residual capacity estimation of fully sealed 25 A h lead/acid cells", pages 305-329 --	
A	International Telecommunications Energy Conference, October 19-22, 1986 Toronto (CA) Debardelaben: "Determining the end of battery life", pages 365-368 --	
A	Chemical Abstracts, vol. 90, 1979 (Columbus, Ohio, US) M.R. Martinelli et al.: "Impedance measurements on sealed lead acid cells", see page	./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
12th September 1990	15 OCT. 1990
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	MISS T. TAZELAAR

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages	Relevant to Claim No.
	144, abstract no. 41266t, & Sci. Tech. Aerosp. Rep. 1978, 16(17) --	
A	Chemical Abstracts, vol. 94, no. 8, 23 February 1981 (Columbus, Ohio, US) see page 185, abstract no. 50281d & JP, A, 80-37831 (AGENCY OF INDUSTRIAL SCIENCES AND TECHNOLOGY) 30 September 1980 --	
A	DE, A, 2540035 (BOSCH) 17 March 1977 ------	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9003052

SA 37708

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 27/09/90
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A- 2540035	17-03-77	None	

EPO FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82